# NONTHERMAL LINEWIDTHS FROM SERTS: IMPLICATIONS FOR CORONAL HEATING MODELS

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## Abstract

Observations from Solar Extreme-ultraviolet Research Telescope and Spectrograph (SERTS) are used to determine the nonthermal velocity in the corona for active and quiet Sun regions in 1991 and 1993. A nonthermal velocity of 20-30 km/s is obtained in all solar structures observed at both observing times. These observations can be used to constrain coronal heating models. The idea that magnetic reconnection could provide energy to heat the non-transient corona is not supported by the data.

## Introduction

The Solar Extreme-ultraviolet Research Telescope and Spectrometer (SERTS) provides spatially imaged spectra of the solar corona with moderate spatial resolution, and high spectral resolution. Both TRACE and Yohkoh observations have clearly demonstrated that there are many structures whose angular size is far below the spatial resolution of SERTS. However, since SERTS can measure spectral the profile of coronal emission lines, the velocity of spatially unresolved plasma elements can be observed. The spatially (or temporally) unresolved structures contribute to the width of the emission line. Linewidth in excess of the Maxwellian width is called the nonthermal width. It contains information about the dynamic of the small-scale features in the corona. Previous observations of the nonthermal width have been reported by Cheng, etal, (1979) and Saba and Strong (1986).

## Description of the Observations

The observations used in this analysis were obtained using SERTS, and are reported by Brosius et al (1996). After eliminating the lines identified by Brosius for which only an upper limit to the linewidth could be determined, one is left with a total 233 emission lines, formed primarily in the temperature range from 1-2 MK, from 5 different solar regions that can be used for this analysis. These are summarized in the Table 1.

**Table 1 Summary of the observations.**

| Observation | Number of Lines |
|---|---|
| AR-91 | 49 |
| QS-91 | 34 |
| Limb-91 | 42 |
| AR-93 | 58 |
| QS-93 | 50 |
| **TOTAL** | **233** |

The data from SERTS has several advantages important for this type of analysis. First SERTS provides the highest spectral resolution available in this wavelength range. The instrument profile of the SERTS spectrometer, measured in the laboratory, is 55 mA. This is much narrower than other available instruments, even SOHO/CDS. Secondly SERTS provides a large number of lines, many from the same ion so that internal checks on the accuracy of the data analysis procedure can be done..

## Results

Consider first the widths determined for different emission lines from the same ionization state of Iron. Observations from the same ionization state of the same element, taken at the same time, should give nonthermal widths that agree. The extent to which they do not provides an indication of the uncertainty in the observation and data analysis procedure. In

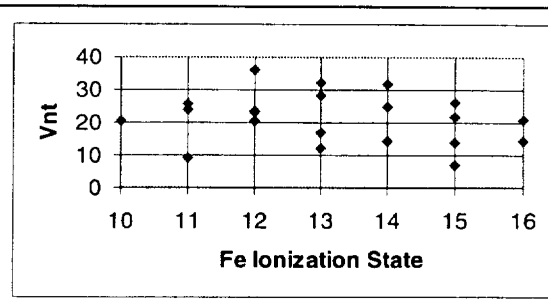


**Figure 1 Nonthermal widths derived for a single active region observation in 1991.**

Figure 1 we have plotted the nonthermal width, obtained by subtracting the SERTS instrument profile measured in the laboratory, and the Doppler width using the temperature of maximum abundance for each ionization state from the total observed linewidth. From this, one can see that the error in the observational determination of the nonthermal velocity from an individual line is of order 15 km/s. This is in rough agreement with the formal error bars obtained from the line fitting procedure.

Widths from the same ion can be converted into velocity units and combined to obtain a single weighted average value, and a combined $1\sigma$ error. An example of the results from this calculation are presented in Figure 2 for three regions observed in the corona. It is obvious from this Figure that the nonthermal velocity in the quiet Sun is essentially the same in the active region, and in portions of the slit observing off the limb of the Sun. There is no evidence of enhanced heating in the active region, and from the limb observation there is no evidence that the motions are primarily transverse. Analysis of similar data taken during the 1993 flight of SERTS gives similar results (see Figure 3).

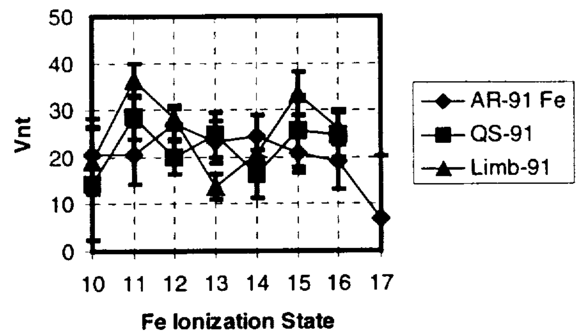


**Figure 2 Nonthermal widths from three different solar features.**

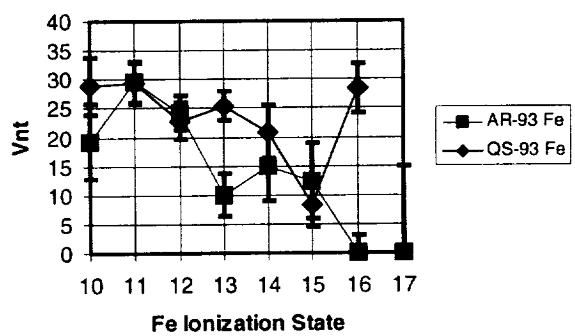


**Figure 3 Nonthermal velocity obtained from observations taken with SERTS in 1993.**

## Implications for Coronal Heating Models

To begin to understand the significance of these results, consider the case where the spectrograph observes unresolved jets due to reconnection, represented by unresolved sheets for simplicity (Figure 4). A characteristic of reconnection in a magnetized plasma is the presence of high velocity jets. A slow flow carries magnetic field and plasma into a thin reconnection region. A pair of hot, high-velocity jets then transport the energy from the reconnecting region. Typically these jets move at a fraction, say 1/3, of the Alfven speed. The Alfven speed in the corona is roughly 2000 km/s, implying jets of order 600 km/s. The corona would be substantially heated by the thermalization of these jet flows. The jet, or the thermalization of these jets would be visible as excess nonthermal linewidth in coronal emission lines, precisely in the hot regions observed by SERTS. The crucial question with regard to the spectroscopic observation however is; how large is the emission measure of the dynamic material?

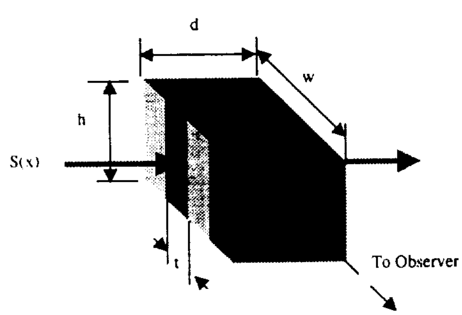


**Figure 4 Idealized model of spatially unresolved reconnection current sheets.**

With this picture in mind, the heating per unit volume is proportional to the divergence of the energy flux, and for a steady state, approximately equal to the radiation loss rate.

$$\oint_S \vec{S} \bullet d\vec{A} = \int_V L_x dV$$

If we consider a volume with dimensions $d \times w \times h$ containing $n$ sheets, each with a thickness $t$, then, using the definitions illustrated in Figure 4, this expression can be written as

$$nthd \frac{dS}{dx} = L_x whd$$

If we then set $\frac{dS}{dx} \approx \frac{S}{\delta}$, where $\delta$ is the beam stopping distance, then

$$\left(\frac{nthd}{whd}\right)\frac{S}{\delta} = \frac{f_V S}{\delta} = L_x$$

The term in parentheses is simply the volumetric fill factor, defined as $f_V$ = emitting volume/total volume along the line of sight. The energy flux is $S = \frac{1}{2} n_e m_H v^3$. For reconnection, $v$ is some fraction $q$ of the Alfven speed, $B_0^2/(4\pi n_e m_H)^{1/2}$. Use this, solve for the electron density to get

$$n_e = \frac{f_v^2}{\delta^2} \frac{(qB_0)^6}{4(4\pi)^3 m_H L_x^2}$$

The emission measure is defined as

$$EM = \int n_e^2 d\ell = n_e^2 \frac{nt}{w} w = n_e^2 f_v w$$

or using the expression developed for $n_e$

$$EM = \frac{w f_v^5 (qB_0)^{12}}{16\delta^4 (4\pi)^6 m_H^2 L_x^4}$$

Numerical estimates for the parameters are $\delta = 10^9 cm$, $w = 10^9 cm$, $L_x = 10^{-2} erg/cm^2$, $B_0 = 100G$, $f_v = 10^{-2}$, and $q = 1/3$. Using these values one obtains a value for the emission measure of

$$EM = 9.5 \times 10^{28} cm^{-5}$$

An emission measure of this magnitude is large, and roughly equivalent to the emission measure of an active region loop.

## Conclusions

Analysis of the SERTS (Solar Extreme-ultraviolet Rocket Telescope and Spectrograph) line profiles, derived from observations of active and quiet Sun from flights in 1991 and 1993 are presented. These data generally show that the non-thermal velocity in the corona is typically less than 30 km/s. There is no significant difference between active and quiet regions. Nonthermal widths observed are the same in 1991 and 1993, even though the corona is generally much hotter in 1991, as evidenced by a time series of Yohkoh pictures taken during this period.

This observation is inconsistent with heating the corona by magnetic reconnection. More realistic and detailed models of reconnection are required if the theory is to be brought into agreement with the observations. Other heating theories for heating the corona require large amplitude, low-frequency MHD waves.

## References

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